# Super-Resolution Algorithms for Ultrasonic NDE Imaging

One of the most desired results from an NDE test of a mechanical part is a segmented image or image cube, showing the locations and physical characteristics of cracks, inclusions, voids, delaminations, ablations, and other flaws. A key NDE goal is to obtain images having the best possible spatio-temporal resolution. Unfortunately, the resolution of all ultrasonic measurements is severely limited by the inherent band-limited spectral transfer function of ultrasonic transducers, the uncertainty principle, and the diffraction limit. In the time domain, the transducer causes severe ringing that greatly limits resolution.

An earlier project prototyped and tested an algorithm that produced an optimal least-squares Wiener estimate of the impulse response of the material under test. The Wiener-based algorithm helped reduce the ringing. Studies have shown that this ringing can be reduced further through the use of advanced super-resolution algorithms.

## Project Goals

The goals of this project are to implement and reduce to practice the Bandlimited Spectrum Extrapolation algorithm in combination with the Wiener algorithm, in an accessible form to provide an important new software tool for NDE applications. The goal for the current effort was to implement the super-resolution algorithm for processing 1-D waveforms, and report the results of tests using simulated data and limited existing programmatic data.

## Relevance to LLNL Mission

Resolution enhancement will directly benefit all LLNL programs that require ultrasonic imaging tests.

## FY2005 Accomplishments and Results

Extensive work was done on a code structure that would allow for a phased implementation effort. The phases to be considered were: the implementation of the super-resolution algorithm; the addition of the Wiener

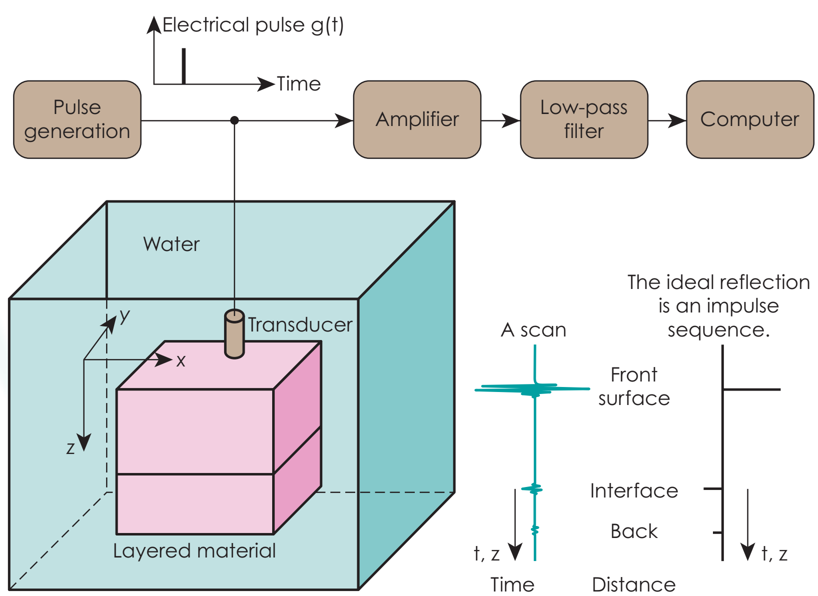


**Figure 1.** Schematic of the ultrasonic image-formation process. A single pulse-echo A-scan is acquired at a fixed position of the transducer. The ideal reflection signal is a sequence of impulses, as shown on the right. The range resolution of the A-scan is limited by the ringing distortion introduced by the band-limited frequency response of the transducer.

For more information contact
**Grace A. Clark**
(925) 423-9759
clark9@llnl.gov

algorithm; extension to 2-D and 3-D data processing; and the addition of a GUI.

The algorithms need to have a number of parameters defined by the user. We have included a user-defined parameter file to control and record the processing on each signal.

The Bandlimited Spectrum Extrapolation (BSE) code was implemented and tested with simulated test signals. The Wiener processing was added, and the entire system was tested on signals from controlled experiments using a known "phantom" part. Figure 1 shows a schematic of the ultrasonic image-formation process.

Figure 2 shows the result of processing a signal acquired from a test phantom containing flat bottom holes. The original measured signal shows a reflection from the front surface of the phantom, followed by reflections from the top and bottom of the hole. The original signal contains ringing at each interface. The impulse response estimated by the Wiener algorithm reduces the ringing, and the Bandlimited Spectrum Extrapolation algorithm nearly eliminates the ringing.

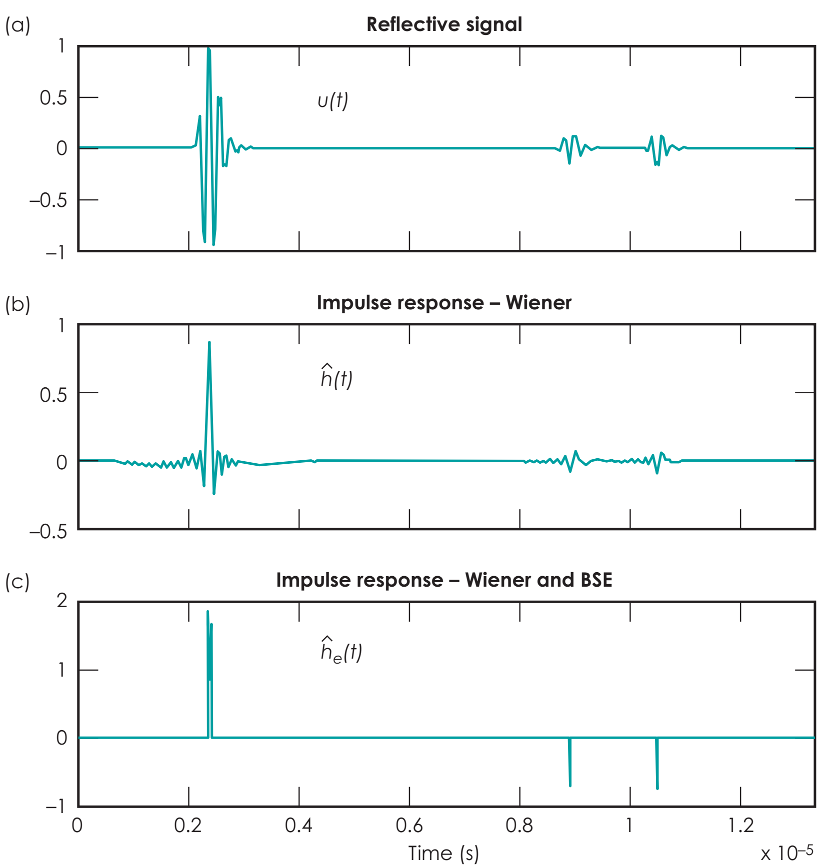


**Figure 2.** Results of processing a signal acquired from a test phantom, an aluminum block with nine known drilled flat-bottom holes. (a) A single reflected signal (A-scan) u(t). (b) The estimated impulse response h(t) of the aluminum block. (c) The extrapolated impulse response $h_e(t)$ of the block, obtained by extrapolating the spectrum of the impulse response estimate. The ringing in the signal is greatly reduced, improving the resolution of thickness measurements and flaw characterizations.

## Related References

1. Clark, G. A., D. M. Tilly, and W. D. Cook, "Ultrasonic Signal/Image Restoration for Quantitative NDE," *NDT International*, **19**, 3, June 1986.

2. Candy, J. V., G. A. Clark, and D. M. Goodman, "Transient Electromagnetic Signal Processing: An Overview of Techniques," Time Domain Measurements in Electromagnetics, E. K. Miller, Ed., Van Nostrand Reinhold Co., New York, pp. 416-455, 1986.

3. Clark, G. A., and F. L. Barnes, "Ultrasonic Signal Resolution Enhancement for Adhesive Thickness Measurements," *Review of Progress in Quantitative NDE*, Williamsburg, Virginia, June 21-28, 1987.

4. Papoulis, A., and C. Chamzas, "Improvement of Range Resolution by Spectral Extrapolation," *Ultrasonic Imaging* 1, pp 121-135, 1979.

5. Youla, D. C., "Generalized Image Restoration by the Method of Alternating Orthogonal Projections," *IEEE Trans. Circuits and Systems, CAS-25*, **9**, September 1978.

## FY2006 Proposed Work

The work for next year will involve the implementation of a user-friendly GUI for the system, and extending the software to include 2-D- and 3-D processing, so we can process volumetric data. Then the algorithms will be extensively tested and validated using existing programmatic data sets.